Evaluation of Explosives Performances on Granite, Calcitic Marble and Dolomitic Marble

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ABSTRACT

The study investigates the performance of different explosives on some selected rock types. To achieve the set objectives, field measurements were conducted using scanline method and clinometers for determining discontinuity spacing and dip, dip direction of discontinuities respectively in Julius Dinga Ltd Iyuku, Geoworks Ltd Igarra and Freedom quarry Ikpeshi all in Akoko-Edo in Edo State of Nigeria. In general there are two sub-vertical joints with the following dips and dip directions, for Julius Dinga Nigeria Iyuku granite are 85° and 344°, 85° and 317°, for Geoworks Igarra calcitic marble are 85° and 041°, 84° and 056° and for Freedom Ikpeshi dolomitic marble are 86° and 321°, 82° and 041° respectively. The in situ block size distribution was also estimated using both empirical and AutoCAD\(^0\). Joint spacing, block volume and volumetric joint count methods were used for empirical block size estimation. Four different types of explosives that is Special gelatine, Emulsion, Slurry and ANFO were used to carry out four blasting operations each on three types of rock selected. Out of the four explosives used, Special gelatine is the most efficient explosive for blasting of granite with efficiency of 64% and over efficient for other types of rock that is it turn them to powder, Emulsion is found the most efficient explosive for blasting of calcitic marble with efficiency of 62%, Slurry is the most efficient explosive for blasting of dolomitic marble with efficiency of 64% and ANFO is found inefficient for all selected rocks except to be used as low explosive combined with other higher explosive.

Keywords: Explosives, Scanline method, clinometers, discontinuity spacing, dip, dip direction, AutoCAD\(^0\), block volume, volumetric joint count.

1. INTRODUCTION

Investigating the performance of explosives (special gelatine, emulsion, slurry and ammonium nitrate) on selected rock types (igneous, sedimentary and metamorphic) is of great importance to mining engineers, in that, rocks are the main components of earth continental crust and these rocks have to be mined successfully for human consumption and development without endangering the environment. The performance of explosives could be determined in two ways, firstly by comparing the velocities of detonations of different explosives on different rocks and secondly by fragmentation analysis - which is the ratio of the in-situ block size distribution to the block size distribution of the muck pile.

Fragmentation is a major concern of any blasting operation. Information on the degree and size distribution of fragments within a blasted rock mass is essential for efficient rock loading and crushing operations. The factors that are important to the fragmentation process are classified into three namely; explosive parameters, rock parameters and charge-loading parameters or blast geometry (Chiappetta, 1991; Thornton, 2002). The explosive parameters include density, detonating velocity, detonation impedance, detonation pressure, gas volume, and available energy. The charge - loading parameters are diameter, length, stemming, decoupling, type of initiation, and point of initiation which play important role in the fragmentation process. Rock parameters that have considerable influence on fragmentation process include density, propagation velocity, characteristics impedance, energy absorption, compressive and tensile strength, variability and structure of the rock (Brady and Brown, 1993).

For a given rock type, geologic structure, and firing sequence, an increase in the degree of fragmentation may be achieved by (a) increasing the consumed quantity of a given explosive, (b) changing to an explosive having greater energy content per unit hole volume (higher energy content/ density), and (c) combinations of both.

For blasting case (a) the associated drilling cost would increase if the explosive quantity were to be increased by simply drilling the same diameter drill holes but on a tighter pattern. Thus there would be more drill holes required to blast a given volume. If larger diameter drill were substituted and the increased hole volume achieved in this way then the rate of increase or decrease would depend upon the comparative drilling cost per foot of hole.

For case (b), assuming that the same hole diameter and pattern are used, the drilling cost would remain constant independent of the fragmentation. For case (c) the drilling cost could remain constant, increase or decrease depending upon the situation.

The engineering model considers four main factors: explosive properties, rock properties, drilling pattern and actual bench geometry. Field data would be used to verify the theoretical development.

In Nigeria little has been done in matching the performance of different type of explosives on different rock types for good rock fragmentation. For this reason, I took pain in carrying out this research work for operators of quarries to choose the best explosives for their operation.
2. MATERIALS AND METHODS

2.1 Explosive Performance on Selected Rocks

2.1.1 Procedure Carried Out to Determine Explosive Performance

The research was conducted on three major rocks which are granite (G), dolomitic marble (D), and calcitic marble (C) all at Ikpeshi in Edo State of Nigeria. Equal areas of deposits of each rock were mapped out. Each deposit of different rocks were further divided into four equal parts (GR1,GR2,GR3,GR4), (DR1,DR2,DR3,DR4), and (CR1,CR2,CR3,CR4). In-situ block size distributions of rock mass of each deposit were measured for each of the selected rocks. Sixteen drill holes were made on each area of the deposits. The drilling design was as follows, Spacing was five feet (1.5m), burden was five feet (1.5m) and depth of hole was 8ft (2.4m). Special gelatine (Gelamon 30), Emulsion (Rock blaster), Slurry (Sun90) and Ammonium Nitrate and Fuel Oil (ANFO-Yara) were the explosives used for the experiments. Other blasting accessories used were detonating cord (12g/m), safety fuse. Same drilling pattern were used and the holes were charged with the same quantity of explosive. Figure 1 presents the methodology used for accessing blast fragmentation.

2.2 Empirical Block Size Distribution

The block size is an extremely important parameter in rock mass behaviour (Barton, 1988; ISRM, 1978). The following are methods used in determining the in-situ block size estimation.

2.2.1 Joint Spacing (S) Method

In other cases where an average joint spacing is used and more than one joint set occurs, the following expression may be used:

\[ V_b = (S_a)^3 \]  

(1)

Here, \( V_b \) = block volume in m³.

Some rock engineers apply the following expression for the average spacing of the joint sets:

\[ S_a = (S_1 + S_2 + S_3 + \cdots + S_n)/n \]  

(2)

where \( S_1, S_2, S_3, \) etc. are average spacing’s for each of the joint sets. But Equation (2) does not correctly characterize the joint spacing.

2.2.2 Block Volume (\( V_b \))

For small blocks or fragments having volumes in cubic decimetre size or less, this measurement is often the quickest.
of the methods, as it is easy to estimate the block size compared to registration of the many joints involved.

Where three joint sets occur, the block volume is

\[ V_b = S_1 \times S_2 \times S_3 / \sin \gamma_1 \times \sin \gamma_2 \times \sin \gamma_3 \]  

(3)

where \( S_1, S_2, S_3 \) are the spacing’s in the three joint sets, and \( \gamma_1, \gamma_2, \gamma_3 \) are the angles between the joint sets.

### Table 1: Block Volume for Various Angles between the Joint Sets

<table>
<thead>
<tr>
<th>All angles = 90°</th>
<th>Two angles = 90°</th>
<th>One angle = 90°</th>
<th>Two angles = 60°</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_b = V_{bo} )</td>
<td>( V_b = 1.16 V_{bo} )</td>
<td>( V_b = 1.3 V_{bo} )</td>
<td>( V_b = 1.5 V_{bo} )</td>
</tr>
</tbody>
</table>

#### 2.2.3 Volumetric Joint Count (\( J_V \))

The volumetric joint (\( J_V \)) count was introduced by Palmstrom in 1982. Earlier, a similar expression for joint density measurements was applied as the number of joints in a blast round. Being a 3-dimensional measurement for the density of joints, \( J_V \) applies best where well-defined joint sets occur.

\( J_V \) is defined as the number of joints intersecting a volume of one m³. Where the jointing occurs mainly as joint sets

\[ J_V = 1/S_1 + 1/S_2 + 1/S_3 + \cdots + 1/S_n \]  

(4)

Where \( S_1, S_2 \) and \( S_3 \) are the average spacing’s for the joint sets.

#### 2.3 Autocad Model

The AutoCAD is automatic computer aided design software used for generating graphic representation of a model. These may be structural or non-structural model. AutoCAD has become a standard program for producing technical drawing of all types, George (2006).

Stages involved in creating this model as suggested by Saliu (2008) were followed in this current study. Those stages are as described below:

a. Pole plot of the fracture data to classify the fractures into sets
b. Determination of Fisher K factor in order to know how parallel the joint in a given set are. The higher the k factor, the more parallel the fractures in a given set.
c. Generate a rectangle with the same surface area (to scale) as the outcrop under consideration.
d. Individual blocks generated by the intercept of the joints are banded together and extruded to the required height based on the distance between sub-vertical features.
e. From the model created, the surface area and the volume of each block is estimated to generate in situ block sizes distribution of the blocks within the required outcrop.

### 3. RESULTS

#### 3.1 Empirical Block Sizes Estimation

Table 1 shows the summary of the estimated empirical block sizes of selected rocks. Figures 2, 3 and 4 show the results of AutoCAD models of Julius Dinga Ltd, Geoworks’ and Freedom quarries respectively.

#### Table 2: Summary of Empirical Block Sizes Estimation of Selected Rocks

<table>
<thead>
<tr>
<th>Rock location</th>
<th>Aver. Spacing (( J_1 )) (m)</th>
<th>Aver. Spacing (( J_2 )) (m)</th>
<th>Aver. Spacing of all sets, ( S_a )(m)</th>
<th>Joint count ( J_V )(1/m)</th>
<th>Joint spacing method (m³)</th>
<th>Block volume method (m³)</th>
<th>Volumetric joint count method (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JDN granite</td>
<td>2.80</td>
<td>3.21</td>
<td>2.50</td>
<td>1.34</td>
<td>15.63</td>
<td>13.48</td>
<td>12.47</td>
</tr>
<tr>
<td>Geowork Calcitic marble</td>
<td>3.14</td>
<td>2.13</td>
<td>2.26</td>
<td>1.45</td>
<td>11.54</td>
<td>10.03</td>
<td>9.84</td>
</tr>
<tr>
<td>Freedom dolomitic marble</td>
<td>1.36</td>
<td>2.0</td>
<td>1.62</td>
<td>1.90</td>
<td>4.25</td>
<td>4.08</td>
<td>4.37</td>
</tr>
</tbody>
</table>
Figure 2: AutoCAD® Drawing of Julius Denga Limited Granite

Figure 3: AutoCAD® Drawing of Geosaurus Nigeria Limited Calcite

Figure 4: AutoCAD® Drawing of Freedom Group Limited Dolomite
3.2 Muckpile Block Size, In-Situ Block Size and Efficiencies of Explosives

Tables 3, 4 and 5 show the values of muckpile block size, in-situ block size and efficiencies of different explosives on selected rocks.

### Table 3: Values of Muckpile Block Size, In-situ Block Size and Efficiencies of different Explosives on Selected Rock Types

<table>
<thead>
<tr>
<th>Rock Sample</th>
<th>Type of Explosive</th>
<th>Muckpile Block Size (m$^3$)</th>
<th>In-situ Block Size (m$^3$)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>Special Gel</td>
<td>5.00</td>
<td>13.86</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>Emulsion</td>
<td>6.93</td>
<td>13.86</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Slurry</td>
<td>8.00</td>
<td>13.86</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>ANFO</td>
<td>10.01</td>
<td>13.86</td>
<td>28</td>
</tr>
<tr>
<td>Calcitic Marble</td>
<td>Special Gel</td>
<td>1.00</td>
<td>10.47</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>Emulsion</td>
<td>4.01</td>
<td>10.47</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Slurry</td>
<td>5.20</td>
<td>10.47</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>ANFO</td>
<td>7.01</td>
<td>10.47</td>
<td>33</td>
</tr>
<tr>
<td>Dolomitic Marble</td>
<td>Special Gel</td>
<td>0.21</td>
<td>4.12</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>Emulsion</td>
<td>1.01</td>
<td>4.12</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Slurry</td>
<td>1.50</td>
<td>4.12</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>ANFO</td>
<td>2.50</td>
<td>4.12</td>
<td>39</td>
</tr>
</tbody>
</table>

### Table 4: Efficiency of each Explosive Used

<table>
<thead>
<tr>
<th>Rock types</th>
<th>Explosive type</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Special Gel</td>
<td>64%</td>
</tr>
<tr>
<td></td>
<td>Emulsion</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>Slurry</td>
<td>42%</td>
</tr>
<tr>
<td></td>
<td>ANFO</td>
<td>28%</td>
</tr>
<tr>
<td>Calcitic Marble</td>
<td></td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>62%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>55%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33%</td>
</tr>
<tr>
<td>Dolomitic Marble</td>
<td></td>
<td>95%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>63%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>39%</td>
</tr>
</tbody>
</table>

### Table 5: Performance of each Explosive Used

<table>
<thead>
<tr>
<th>Rock types</th>
<th>Explosive type</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Special Gel</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Emulsion</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>Slurry</td>
<td>Fair</td>
</tr>
<tr>
<td></td>
<td>ANFO</td>
<td>Poor</td>
</tr>
<tr>
<td>Calcitic Marble</td>
<td></td>
<td>Extreme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fair</td>
</tr>
<tr>
<td>Dolomite Marble</td>
<td></td>
<td>Extreme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fair</td>
</tr>
</tbody>
</table>

4. DISCUSSION

4.1 In-Situ Block Size Distribution

#### 4.1.1 Empirical Block Size Estimation

The general joint pattern shows that two main sub-vertical joints ($J_1$ and $J_2$) were dominant in all the selected rock as shown in the pole plots below. The sub-horizontal feature, ($J_3$) varies in spacing from selected site to site and 1500cm spacing, which was the minimum spacing observed from all the sites visited was used as the spacing for sub-horizontal feature ($J_3$) in the empirical block size estimation. The block sizes (cm$^3$) were estimated using joint spacing, block volume and volumetric joint count methods.

The results of JDN granite, Geoworks calcitic marble, and Freedom dolomitic marble are shown in Table 1, from which it can be observed that JDN granite and Geoworks calcitic marble had larger average block size when compared to Freedom dolomitic marble. This can be attributed to the differences in their fracture patterns. JDN granite and Geoworks calcite were observed to have wider spacing of sub-vertical fracture compared to Freedom dolomite. This
shows that the spacing of sub-vertical joints has the most significant effect on the ability of rock in-situ to produce blocks that meet the required specifications.

Another observation of interest is the relationship between the volumetric joint counts and the average in-situ block sizes. It can be observed that the JDN granite and Geoworks calcitic marble which had larger block sizes are having low volumetric joint counts while the Freedom dolomite marble that had the small average block sizes had high volumetric joint counts. This follows the observation of Sousa (2007) who noticed that the higher the volumetric joint counts the lower the tendency of producing a bigger blocks.

Based on the three methods used in this work for empirical block size estimation, it can be observed that the average block sizes obtained using the joint spacing method is always higher than the value obtained when using block volume and volumetric joint counts. This also agreed with the observation of Palmstrom (2005) who stated that the average block size obtained from joint spacing method must be used with care as it often exaggerates the block size. Therefore, this exaggeration must be carefully taken care of when using the joint spacing method of block size estimation.

4.1.2 Numerical Modelling

Numerical modelling of in-situ block size distribution of selected rocks results are shown in Appendix. The analyses were based on the minimum acceptable surface area of 2m² of block size as proposed by Luodes et al. (2000). The colour as used in the model is for easy identification of each block formed by the interception of fractures. The results of the analyses showing the in-situ block size distribution are provided in Figures (2, 3, and 4). Modified volumetric joint counts were used in this research work since the modelling was based on the surface area created only by sub-vertical joints. Sub-horizontal fractures were not considered because of their disappearances as the depth increases and it thus has no limiting effect on in-situ block size.

From AutoCAD® modelling results of selected dolomitic marble, calcitic marble and granite, it can be observed that in Julius Dinga Limited granites, random jointing was observed in addition to the two sub-vertical joints, while in Freedom Group Limited dolomite marble and Geoworks’ Limited calcitic marble, two regular sub-vertical fractures existed throughout the outcrop.

Freedom dolomite and Geowork’s calcite were observed to have smaller block sizes when compared to Julius Dinga Limited granite from the model results summarized in Figures 2, 3, and 4. This can be attributed to difference in joint spacing. It was observed from the AutoCAD® model that sub vertical joints in Julius Dinga Limited are more widely spaced as compared to Freedom Group Limited and Geoworks’ Nigeria Limited and thus results in formation of blocks of larger size in Julius Dinga Limited which explain the differences in their in situ block sizes.

The in-situ block size distributions of Julius Dinga Limited, Freedom Group Limited and Geoworks’ Nigeria Limited are shown in the figure below. From this figure, it can be observed that majority of the blocks fall between 2m² and 6m² which agreed with earlier observation from empirical block size estimation.

4.2 Muckpile Block Sizes

Product of various blasting carried out on granite, calcitic marble and dolomitic marble with four different explosives (Special Gel, Emulsion, Slurry and ANFO) are shown in Plates 1 to 12.

Plate 1D shows the product of granite blasted with special gel, the blasting results show that the efficiency of blasting granite with special gel is very high and the muckpile sizes are well distributed, this indicate a very good blasting product as compared to other three explosives (Emulsion, Slurry and ANFO) used on this same rock. Although, emulsion also performed very well but not as efficient as the special gel but slurry and ANFO give poor product. Therefore, special gel is recommended when blasting granite rock.

Plate 5D shows the product of calcitic marble blasted with special Gel, the blasting results show that the efficiency of blasting calcite marble with special gel is too high and the product obtained have more dust which is a lost to the quarry. Plate 6D shows the product of blasting using Emulsion, this gives the most efficient result the efficiency is 62%. Plate 7D shows the product of blasting using Slurry the result obtained shows that the explosive is less effective for blasting of calcite because the efficiency is 55% which is small as compared to that of emulsion and Plate 8D shows the product of blasting with ANFO this give more boulders than expected, the efficiency is below 30% which shows ineffectiveness of this type of explosive for production blasting.

Plate 9D to 15D show the product of blasting dolomitic marble using four explosive that is special gel, emulsion, slurry and ANFO. The blasting results obtained using those explosives on dolomite marble rock shows that the most efficient explosive for this type of rock is slurry its efficiency is 64%. It gives a very good muckpile size distribution.

The efficiencies of each explosive and their respective performance on each type of rock blasted as calculated below are written in Tables 3, 4, and 5.

Performance of Explosives = 100 - \left( \frac{\text{Muckpile block size}}{\text{In situ block size}} \right) \times \frac{100}{1} \% \quad (5)

(a) To calculate percentage performance of different explosives on Julius Dinga Limited granite rock sample

(i) Special gel = 100 - \left( \frac{5.00}{13.86} \right) \times \frac{100}{1} = 64\%
Plate 1: Product of Blasting in Julius Dinga Limited with Special gel

(ii) Emulsion = 100 - \( \frac{6.92}{13.86} \) \( \times \) \( \frac{100}{1} \) \% = 50\%

Plate 2: Product of Blasting in Julius Dinga Limited with Emulsion

(iii) Slurry = 100 - \( \frac{9.00}{13.86} \) \( \times \) \( \frac{100}{1} \) \% = 42\%

Plate 3: Product of Blasting in Julius Dinga Limited with Slurry

(iv) ANFO = 100 - \( \frac{10.01}{13.86} \) \( \times \) \( \frac{100}{1} \) = 28\%
(b) To calculate percentage performance of different explosives on calcite rock sample

(i) Special gel = $100 - \left(\frac{100}{1.01}\right) \times \frac{100}{1} \% = 90\%$

(ii) Emulsion = $100 - \left(\frac{4.01}{10.47}\right) \times \frac{100}{1} \% = 62\%$
(iii) Slurry = 100 − \(\frac{5.20}{10.47}\) \(\times\) \(\frac{100}{1}\) \% = 55%

Plate 7: Product of Blasting in Geoworks’ Nigeria Limited with Slurry

(iv) ANFO = 100 − \(\frac{7.01}{10.47}\) \(\times\) \(\frac{100}{1}\) \% = 33%

Plate 8: Product of Blasting in Geoworks’ Nigeria Limited with ANFO

(c) To calculate percentage performance of different explosives on dolomite rock sample

(i) Special gel = 100 − \(\frac{0.21}{4.12}\) \(\times\) \(\frac{100}{1}\) \% = 95%

Plate 9: Product of Blasting in Freedom Group Limited with Special Gel
(ii) Emulsion = $100 - \left( \frac{1.01}{4.12} \right) \times \frac{100}{1} \% = 76\%$

Plate 10: Product of Blasting in Freedom Group Limited with Emulsion

(iii) Slurry = $100 - \left( \frac{1.50}{4.12} \right) \times \frac{100}{1} \% = 63\%$

Plate 11: Product of Blasting in Freedom Group Limited with Slurry

(iv) ANFO = $100 - \left( \frac{2.50}{4.12} \right) \times \frac{100}{1} \% = 39\%$

Plate 12: Product of Blasting in Freedom Group Limited with ANFO
5. CONCLUSION

From the fracture characterization carried out on the selected sites, it was observed that two main sub-vertical joints (J₁ and J₂) were dominant in all the three selected rocks.

The results of empirical estimation of average in-situ block size distribution using joint spacing, block volume and volumetric joint count methods, all agreed that JDN granite and Geoworks calcite have larger average block size and Freedom dolomite has smallest block size.

The results of numerical modelling also agreed with the results of empirical estimation with JDN and Geoworks having the biggest average block size and Freedom dolomite being the smallest.

Muckpile sizes distributions were also determined. The results show that the best explosive suitable for granite rock to obtain efficient muckpile distribution is special gel, that of calcite is emulsion and that of dolomite is slurry as shown in Table 3, 4 and 5.

REFERENCES


DIP PLOT AND BLOCK SIZES

Julius Dinga Limited Dip Plot, and block sizes

Figure 5: Pole Concentration Plot of Julius Dinga Limited, Granite

Figure 6: Major Joints Planes and Poles of Julius Dinga Limited, Granite
Geoworks Calcite Dip Plot, and block sizes

Figure 7: Pole Concentration Plot of Geoworks Calcite Marble

Figure 8: Major Joints Planes and Poles of Geoworks Calcite Marble
Freedom Quarry Dip Plot, and block size distribution

![Dip Plot](image)

**Figure 9: Pole Concentration Plot of Freedom Dolomitic Marble**

![Joint Planes](image)

**Figure 10: Major Joints Planes and Poles of Freedom Dolomitic Marble**